NATIONAL ACADEMY OF SCIENCES

Number 46 • April 1961

IGY BULLETIN

A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation–1959 as related primarily to United States programs. The Bulletin *also reports on international programs in geophysics and space science that have grown out of the IGY, and on their results.*

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Arctic Basin Seismic Studies from IGY Drifting Station Alpha

The following material is based on a report by Kenneth Hunkins, Lamont Geological Observatory, Columbia University. The original, more-detailed report, prepared by Lamont for the Geophysics Research Directorate of the Air Force Cambridge Research Laboratories, was published as AFCRC-TN-60-257, Seismic Studies of the Arctic Ocean Floor, *October 1960.*

Reflection and refraction seismic measurements made between July 1957 and November 1958 from IGY Drifting Station Alpha, built on pack ice in the Arctic Ocean, revealed details of a prominent submarine rise, referred to in this report as the Alpha Rise. This series of seismic investigations also provided information about the nature of the earth's crust beneath the ocean floor to a depth of about 3.5 kilometers.

First occupied by IGY scientific personnel in the spring of 1957, Station Alpha was abandoned in November 1958 when pressures within the ice pack destroyed the floe on which the station was constructed. During its period of occupation for IGY geophysical investigations, Station Alpha drifted along an irregular track in the North Canadian Basin, approximately within the region 83°–86° N, 115°–175° W, under the influence of ocean currents and wind. (See Figure 1.) The station's position was determined daily by astronomic fixes when cloud conditions permitted.

(Additional information on IGY Drifting Station Alpha and on its scientific programs may be found in *Bulletin Nos. 1, 4, 6, 12, 17, 22,* and *24. Bulletin No. 4* contains a preliminary report on early observations of the Alpha Rise from Drifting Station Alpha; *Bulletin No. 22* presents a preliminary report by Hunkins on the studies described in the present report [and in a report on Arctic Ocean bottom gravel, which will appear in the next issue of the *Bulletin*]; and *Bulletin No. 24* carries an analysis of ice drift in the Arctic Basin. *Bulletin Nos. 33* and *34,* which contain a two-part review of the IGY Seismology Program, explain the technique of explosion seismology and the primary uses of its two major types—reflection and refraction.)

The Station Alpha seismic studies described below were directed by Kenneth Hunkins, of Lamont Geological Observatory, under a contract from the Geophysical Research Directorate of AFCRC. Assistance in the field work was provided by Maurice Davidson, Frans van der Hoeven, Gary Latham, and Bryan Isaaks, all of Lamont, and Jack Oliver, director of Lamont's Arctic geophysics project, gave valuable advice toward analysis and interpretation of the results. Air Force personnel

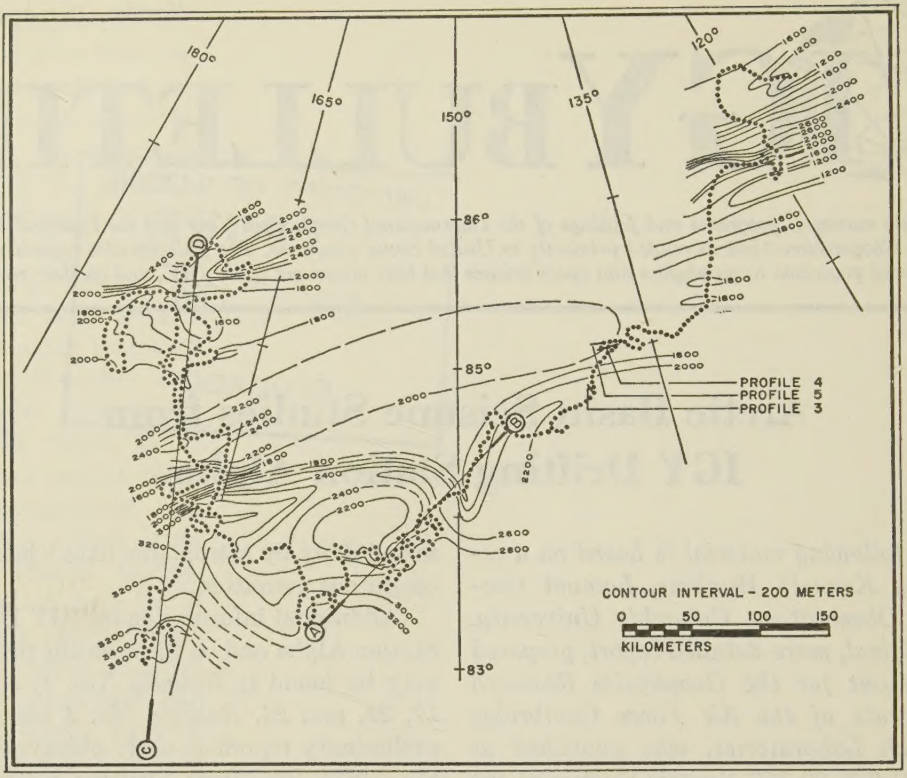

Fig. 1. *Bathymetric Chart of Arctic Basin along Track of IGY Drifting Station Alpha, June 1957–November 1958. Dots indicate station's drift path; contour interval is 200 meters. A-B and C-D are lines along which corresponding profiles in Figure 2 were drawn, and numbers 3, 4, and 5 represent locations of structure sections in Figure 3.*

contributed important cooperation and assistance.

Reflection Studies

Vertical reflection soundings were made daily in winter and twice daily in summer, and, as the floe's average drift was 5½ km per day, these soundings were usually spaced from 2 to 6 km apart along the irregular track. Unusually calm or windy periods resulted, of course, in closer or wider spacing. Sounding positions were interpolated between astronomic fixes and most are accurate to 1 km, but occasional periods of persistent cloud cover lasting several days reduced the number of fixes and, in places, lowered accuracy to 2 to 4 km. For the reflection shots, quarter-pound charges of dynamite were exploded at a depth of 3 meters below the water surface.

Bottom Reflections: The reflection soundings produced information on dip and strike of the bottom as well as on its depth. (Strike here refers to the horizontal trend of the bottom structure, and dip to the bottom slope at right angles to the strike.) A total of 623 sonic soundings were made and, of these, 555 yielded dip and strike information. The measured dips and strikes represent the attitudes of 150-meter-square areas of the ocean floor. Bottom dips ranged from 0° to 22°. The average dip was 2.70°, with a standard deviation of 2.25°, and most dips were between 0.5° and 1.5°.

The seismic depths obtained are accurate to less than one meter, and wire soundings taken at Station Alpha are in close agreement with the sonic soundings. All bottom

reflections observed appear to indicate that the characteristic impedance (density × sound velocity) of the topmost sediment is greater than that of water. A sediment layer with an impedance less than that of water would probably have a thickness of less than about four meters.

Throughout its occupation, Station Alpha drifted over the submarine feature here named Alpha Rise (after the station). At the beginning of its occupation, the station was immediately south of the rise in more than 3000 meters (nearly 10,000 feet) of water. The maximum depth recorded was 3871 meters, at 82° 48′ N, 167° 01′ W. Its initial northward movement carried the station over the rise at almost right angles to its trend.

After reaching 85° 32′ N, 171° 10′ W in its northward drift, the station turned northeastward and moved nearly along the trend of the rise. Toward the end of the period of occupation of Station Alpha, the shallowest depth of 1140 meters was recorded, near the eastern end of the rise at 86° 09′ N, 114° 08′ W. The drift patterns of Station Alpha permitted detailed bathymetry for several areas of the rise, and a bathymetric chart (Fig. 1) was contoured with the aid of dips, strikes, and depth information.

The broad outline of the Alpha Rise was known previously from observations from Soviet drifting station NP–4 (1954) and from soundings of the USSR High Latitude Aerial Expeditions. The rise trends northeast-southwest across the Arctic Ocean from the edge of the continental shelf north of Wrangle Island to the shelf off Ellesmere and Axel Heiberg Islands. The Alpha Rise is sub-parallel to the Lomonosov Ridge and is twice as broad as that feature, or about 200 kilometers wide. Its crest is at shallower depths than present maps indicate: the minimum sounding over the central portion of the rise was 1426 meters, at 85° 03′ N, 171° 00′ W. To the north and south of the rise lie basins with depths greater than 3000 meters.

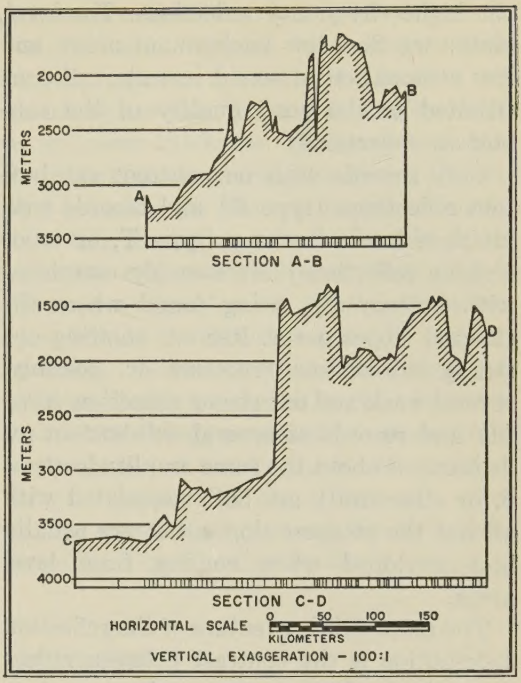

Fig. 2. *Bathymetric Profiles across the Alpha Rise. Vertical exaggeration is 100:1. Locations of profiles shown in Figure 1.*

Dip information and bathymetric profiles show that the topography of the rise is rugged (Fig. 2). The profiles strongly suggest that this is an area of fault-block mountains, although the Alpha Rise lies in an aseismic part of the Arctic Ocean and is not tectonically active at the present time.

Topographic Echoes and Sub-bottom Reflections: Several bottom echoes, or topographic echoes, are present in many of the reflection records. They occur in areas of rugged topography where several reflectors return echoes from different locations. Characteristically, the first reflection is low in amplitude and indicates a steep dip, as it comes from a topographically elevated area having relatively small reflecting surfaces. The principal bottom echo arrives shortly afterward, is of greater amplitude, and shows a flatter dip.

Sub-bottom reflections are present in the majority of the reflection records. They occur as lower-frequency events following

the higher-frequency reflections. The level, stable ice floe, low background noise, and low attenuation of sound in water all contributed to the good quality of the sub-bottom reflections.

Only records with no coherent sub-bottom reflections (type R) and records with multiple bottom echoes (type T, or topographic reflections) are strongly correlated with bottom dip, being found where the steepest slopes occur. Records showing one strong sub-bottom reflection or, possibly, several weak and one strong reflection (type M) and records of several sub-bottom reflections of about the same amplitude (type S, or structural) are both associated with all but the steepest slopes, but are usually best-developed when coming from level areas.

The most striking feature of the reflection distribution is the contrast between reflections obtained on eastern and on western crossings of the Alpha Rise. For the western crossing, reflections are principally type S, with few topographic echoes. The oblique eastern crossing produced principally type M and type T records. This variation in record type cannot be due to instrumental factors or to technique, as the same instruments and shooting technique were used for all of the field work. Thus, the variation must indicate a stratigraphic or structural difference between the eastern and western ends of the Alpha Rise.

The type T records show that bottom texture is rougher in the eastern area. The M reflection in the eastern area probably corresponds to a "second reflection," observed several years earlier by A. P. Crary and N. Goldstein from ice-island T-3 in the area 84°–88° N, 70°–100° W. They found this "second reflection" 210–340 meters below the bottom. It is likely that the kind of bottom topography producing the type M reflections recorded from the eastern Alpha Rise by Station Alpha investigators continues eastward to the area covered by T-3.

The strong type M echo indicates a good impedance contrast, probably representing the interface between the unconsolidated sediments and the underlying rock. In the western area, where a single strong reflection is absent, the impedance contrast at the base of the sediment may be low due to an underlying rock having properties little different from the overlying sediment. The reflections of the type S record would, if this were the case, result from layering within the unconsolidated sediment.

Refraction Studies

During the spring and summer of 1958, five unreversed refraction stations were made at Drifting Station A. Of these stations, the last three (see Fig. 1) recorded the refracted ground wave as a "first arrival." The charges used ranged from 25 to 75 pounds of TNT fired about 2 to 3 meters below the water surface, and the right-angle array of geophones permitted measurement of the apparent velocities and azimuths of the arrivals. Figure 3 summarizes graphically results of the three refraction profiles discussed below.

Refraction Profile No. 3: On July 25, 1958, a refraction station was made in the vicinity of 84° 45′ N, 140°W. The ocean bottom beneath the receiver was at a depth of 2085 meters and had a dip of 6°. The interpreted structure section shows the water column to be underlain by 0.48 km of sediment with a seismic-wave velocity of 2 km/sec; below this lies an undetermined thickness of material with a velocity of 5.52 km/sec.

On several reflection records taken in the vicinity, a type M sub-bottom reflection appears and, in the vicinity of the profile, the depth to this horizon is about 200 meters.

Refraction Profile No. 4: A profile of three shots was made on August 2, 1958, in the vicinity of 85° N, 138°–139° W. The vertical-reflection record at the receiver showed 1813 meters of water and a bottom dip of 2°. A sub-bottom reflection at 342 meters was also shown, and the indicated

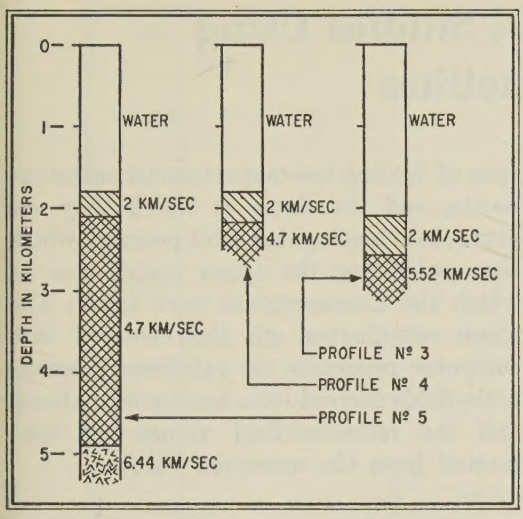

Fig. 3. *Structure Sections for Refraction Profiles, on the Alpha Rise. Seismic-wave velocities of bottom materials and underlying bedrock are shown. Profile locations indicated in Figure 1.*

reflection horizon dipped more steeply than the bottom. Low-angle reflections indicated high topography between the closest shot point and the receiver. The interpreted structure indicates that directly beneath the water column is a layer of 2 km/sec material 0.37 km thick, underlain by an undetermined thickness of 4.7 km/sec material.

The prominent reflection horizon at 342 meters at the receiver site, and 350 meters near the shot point, agrees closely with the 370-meter thickness of the 2 km/sec layer found by refraction. Apparently this prominent reflector is the base of the upper low-velocity sediment in this area.

Refraction Profile No. 5: A profile was made on August 3, 1958, very close to the area of Profile No. 4. Interpretation of the results shows 0.29 km of 2 km/sec sediment lying upon 2.8 km of 4.7 km/sec material. Below this lies a 6.44 km/sec layer of unknown thickness. The prominent sub-bottom reflection horizon is about 350 meters beneath the bottom in this vicinity.

In this profile, and in Profile No. 3, the reflection and refraction soundings lead to different values for the depth of the unconsolidated sediment layer. It appears probable, however, that both methods measure depth to the same interface, but that simplifying assumptions (concerning horizontality of bedding and a wave velocity of 2 km/sec in the sediments), when applied to the data received by each technique, lead to differing results.

Conclusions

The Alpha Rise is one of the large positive features of Arctic Ocean topography. Relief on the rise is rugged and is apparently the result of block faulting. Although only three short refraction profiles supplied crustal data, they tend to show results similar to those reported for the North Atlantic Ocean by J. Ewing and M. Ewing, 1959.

The average thickness of the upper, or unconsolidated, layer of bottom material was 0.38 km, as compared to ½ to 1 km in the North Atlantic. A single measurement indicating a thickness of 2.8 km was made for a deeper, 4.7 km/sec layer. The seismic-wave velocity of the deeper, "oceanic" layer was 6.44 km/sec, which is in close agreement with the velocity of about 6.5 km/sec found in the North Atlantic.

Geomagnetic-Field Studies Using Earth Satellites

The following report is based on a paper by J. P. Heppner, J. C. Cain, I. R. Shapiro, and J. D. Stolarik, presented at the Twelfth General Assembly of the International Union of Geodesy and Geophysics (IUGG), held in Helsinki, Finland, July 1960. The authors of the paper are associated with the Goddard Space Flight Center of the National Aeronautics and Space Administration.

The Vanguard III satellite (1959 Eta), launched on September 18, 1959, by the Goddard Space Flight Center, carried a specially designed proton-precessional magnetometer to help chart the earth's magnetic field in space. (See *Bulletin No. 28.*) The lifetime of the experiment was approximately three months (September 18—December 12, 1959), during which numerous magnetic-field measurements were made throughout an altitude range of about 510–3750 kilometers (about 320–2330 statute miles) and between geographic latitudes of 33.5° N and S and geomagnetic latitudes of 45° N and S.

During Vanguard III's 85 days of operation, approximately 4300 successful responses to ground commands (about 50 per day) were recorded by the Minitrack stations. Each command yielded one proton-precessional signal of approximately two-seconds duration, and, from tapes thus far played back, it appears that 80% of the signals will yield measurements of high accuracy.

Analyses of the data collected by Vanguard III are contributing to evaluations of the accuracy of magnetic charts and computed geomagnetic fields, determinations of possible discontinuities in the earth's magnetic field, and further knowledge of geomagnetic storms and their effects. The data-reduction procedure consists of feeding the magnetometer measurements, and the times at which they are taken, into a computer orbit program which then calculates the space coordinates at which the measurements were taken. The space coordinates are then entered into computer programs for reference geomagnetic-fields derived from harmonic analyses, and the reference-field values are subtracted from the measured values.

Accuracy of Magnetic Charts and Computed Geomagnetic Fields

A by-product of using computed fields for reference is that information is gained that relates directly to some long-standing questions in geomagnetism pertaining to analysis of the earth's main magnetic field. The first of these concerns the accuracy with which fields in space can be computed from analyses of surface charts. A general answer based on a preliminary review of the Vanguard III measurements is that the average error is about 1%. This is in general agreement with opinions expressed prior to the experiment by E. H. Vestine and others. The 1% figure also indicates that the charts used in deriving coefficients are in error by at least 1% in low latitudes. As noted by D. C. Jensen and W. A. Whitaker, the errors in some regions are probably much greater.

A second question of long standing in geomagnetism is whether significant field effects occur at altitudes of several thousand miles, within geographical dimensions comparable to those represented by the higher-order terms of computed fields. The answer is definitely "yes," in some regions, unless external field sources at similar altitudes are postulated. The satellite data obtained over southern Australia clearly illustrate this. In these data, curves for the

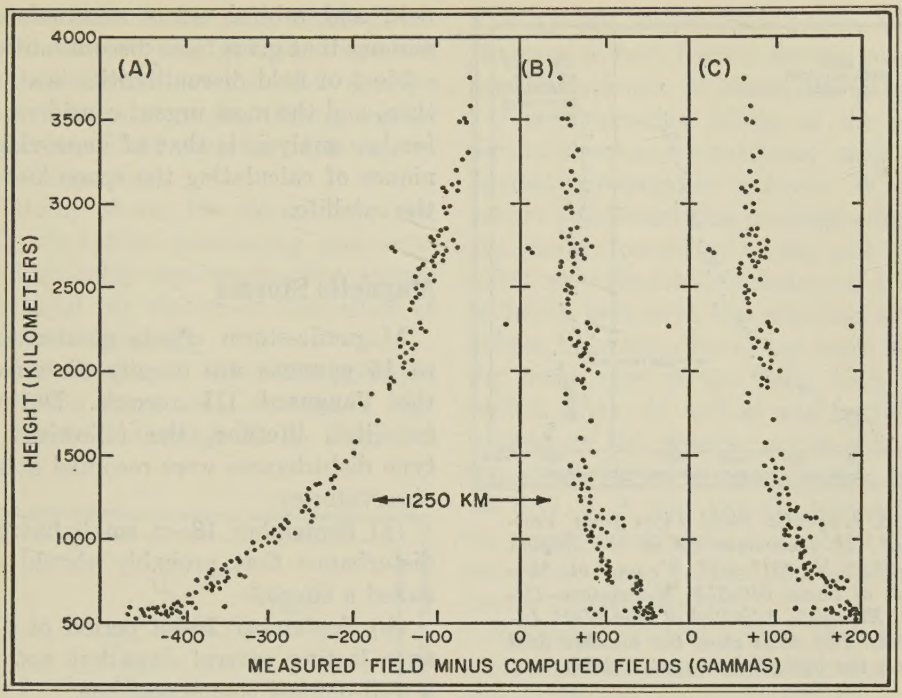

Fig. 4. *Magnetic Field Plots from Vanguard III Measurements in the Region 32°–33.5° N, 111°–121° W, and at Altitudes of about 510–3750 Kilometers—Orbital Elements Adjusted at One-Month Intervals. The plots show the field measured by the satellite minus computed fields as follows: A, using coefficients of H. F. Finch and B. R. Leaton; B, using coefficients of D. C. Jensen and W. A. Whitaker, based on US Navy Hydrographic Office charts; and C, using Jensen and Whitaker coefficients based on Russian magnetic charts.*

same latitude range are clearly shifted relative to each other over several degrees of longitude at altitudes up to 2000 miles.

Field Discontinuities

Magnetic-field discontinuities of a permanent or semi-permanent nature are not expected to be found between altitudes of 510 and 3750 km, since diamagnetic effects in the inner radiation belt are expected to be too small and most drift theories place currents at greater altitudes. However, following a computer run in May 1960, the attention of the investigators was directed to the possibility of a field discontinuity at the lower edge of the inner Van Allen belt. Nearly all of the plots of the type in Figures 4 and 5 showed obvious discontinuities or slope changes in the region 1250–1600 kilometers.

Additional interest was generated when it was found that the largest field changes during magnetic storms occurred in the boundary regions of the inner belt (discussed below). A confusing factor was that the majority of the discontinuities occurred either at adjustments of orbital elements in the computer program or when data on opposite sides of such adjustments were not continuous with time. However, several exceptions were found in which the data were continuous with time, and these exceptions, together with the similarity of behavior of a large number of curves, led the investigators to believe, with considerable reservation, that a field discontinuity was present at the lower edge of the inner Van Allen radiation belt.

As a further test, new orbital arcs were evaluated, in July 1960, over monthly (Fig. 4) rather than weekly (Fig. 5) intervals,

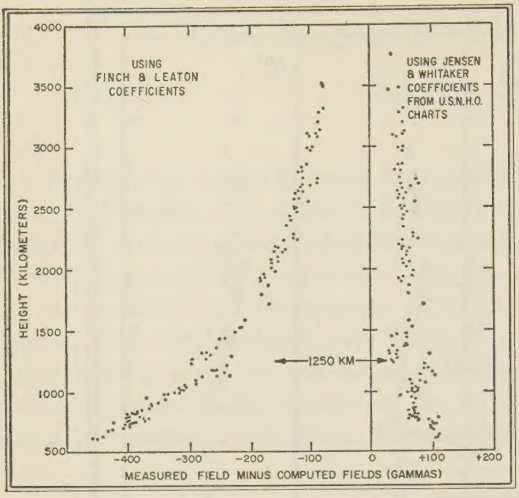

Fig. 5. *Magnetic Field Plots from Vanguard III Measurements in the Region 32°–33.5° N, 111°–121° W, and at Altitudes of about 510–3750 Kilometers—Orbital Elements Adjusted at One-Week Intervals. The plots show the satellite field minus the indicated computed fields.*

thus reducing the number of discrete orbital transitions from eleven to two. The principal effect of the new computation in comparison with the old was that a number of the sharp discontinuities in the 1250–1600 km range disappeared. Figures 4 and 5 provide a striking example of this difference at an altitude of 1250 km.

The disappearance of discontinuities when one-month orbital arcs are used makes the existence of a permanent discontinuity at the lower edge of the inner belt appear very doubtful. In spite of this, the possibility cannot be dismissed. Most curves of field difference with altitude still show a maximum rate-of-change of slope in the 1250–1600 km range, and, in some regions, the change from weekly to monthly orbital arcs did not greatly alter the appearance of the curve. Thus, for the portion of Vanguard III's orbit passing over southern South America, near the region where the magnetic field at the earth's surface is at a minimum, it must be assumed that either there are field discontinuities or that the various effects due to reference-field and orbital errors accumulate in a manner that gives false discontinuities. The subject of field discontinuities is still open, then, and the most urgent consideration for further analysis is that of improving techniques of calculating the space location of the satellite.

Magnetic Storms

Magnetic-storm effects greater than 10 to 15 gammas are usually discernable in the Vanguard III records. During the satellite's lifetime, the following storm-type disturbances were recorded at surface observatories:

(a) September 18—a small but general disturbance that probably should not be called a storm.

(b) September 20—a period of disturbance lasting several days but not having a well-defined commencement.

(c) October 3—a period of disturbance having a gradual onset but with the horizontal component of the earth's magnetic field depressed uniformly with latitude over a number of hours.

(d) October 30—sharp SC (sudden commencement of a magnetic storm) at 23:48 GMT on October 29, followed by several days of weak-to-moderate disturbance.

(e) November 28—sharp SC at 23:51 GMT on November 27 (shown in Figure 7).

(f) December 5—sharp SC at 07:00 GMT on December 5, followed by large disturbance of classical appearance in the horizontal component.

In (a), (b), and (d), most of the readings do not deviate from the values for magnetic quiet periods. A close examination, however, does indicate that disturbances up to 20 gammas may often be present. The sign of these small deviations is more often negative than positive when the horizontal component on the ground is negative, but the correlation is poor. The most notable exceptions to the generally small magnitudes occur for storm (d) in measurements obtained on two satellite

passes near latitude 20° S in which deviations of —40 to —70 gammas occurred. On the other hand, several other satellite passes in the same region during similar disturbed conditions recorded deviations of less than 20 gammas.

The storm effects for storms (c), (e), and (f) are rather outstanding and peculiar, and probably demonstrate why storms (a), (b), and (d) showed so little effect at the satellite's position.

Storm of October 3, 1959: The principal effects of this storm are illustrated in Figure 6. Points 1 through 15 in Figure 6

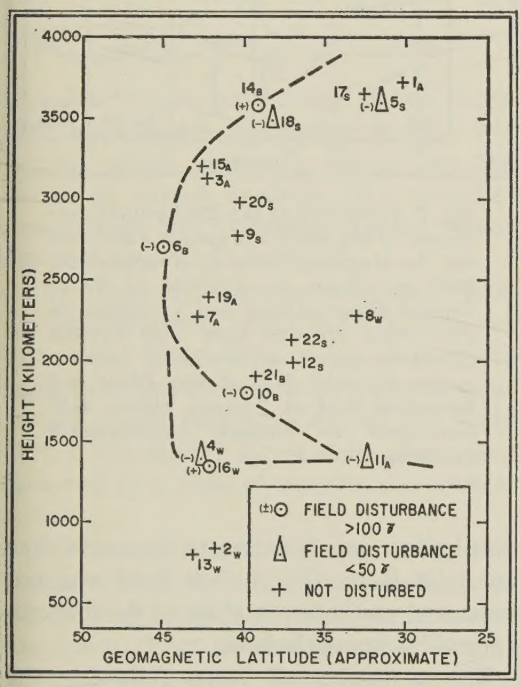

Fig. 6. *Geomagnetic-Field Disturbance during Storm of October 3, 1959. Satellite measurements received at various tracking stations are plotted (in terms of relative intensity of disturbance) against altitude and geomagnetic latitude. S indicates San Diego station; B, Blossom Point; A, Antigua; and W, Woomera.*

represent, chronologically, all readings taken from the time the storm showed an appreciable disturbance in the horizontal component on the ground to a time just before most ground observatories recorded a sharp recovery to zero from a horizontal-component disturbance of about 100 gammas.

The disturbance effects at the satellite do not show any consistency until plotted against geomagnetic latitude. When this is done it is found that readings affected by the storm (points 4, 6, 10, and 11), lie either near the lower boundary of the inner radiation belt or in the radiation slot that defines the outer edge of the inner belt and the inner edge of the outer belt. Undisturbed points (1 and 2) can probably be ignored as the disturbance at the ground was small. However, points within the belt (3, 5, 7, 8, 9, and 12) all occurred when the negative horizontal-component disturbance was large (about 100 gammas) at nearby ground stations.

Following point 12 in time, the horizontal component returned suddenly to zero at ground observatories in low latitudes over most of the earth; following this unusual happening, in turn, the horizontal component again became negative and was irregular for another day. Points 13 through 22 represent, in time sequence, the measurements taken at geomagnetic latitudes greater than 25° during this period. Points 14 and 16 were disturbed by +170 and +120 gammas, respectively, during times when the horizontal component was negative at nearby ground stations. Points 15, 19, 21, and 22, which were not disturbed, occurred during times when the horizontal component was similarly depressed, and points 13, 17, 18, and 20 occurred when the disturbance was very small.

Readings at low latitudes were confined to the beginning of the disturbance (prior to point 1) and to a period between points 12 and 13 when the disturbance was small. These times also correspond to local times of equatorial electrojet activity in South America. The readings were either undisturbed or disturbed by —10 to —20 gammas, with the exception of a measurement of +40 gammas near the start of the disturbance.

Storm of November 28, 1959: The behavior of this storm is illustrated in Figure 7 in the conventional manner of showing the horizontal component from several observatories. Total-field records from two stations are also shown to illustrate, first, the similarity of appearance of the total field at San Diego and the horizontal component at Tucson, and second, the behavior of the total field when a large vertical-component variation is present at a station at a magnetic latitude greater than 40°.

Used in conjunction with Table 1, Figure 7 constitutes a reference of disturbance against time for the satellite measurements. With the exceptions of I, K, L, and M, the readings were taken in the same general regions as the records shown in Figure 7.

Six points in Figure 7 (A, B, C, G, I, and L) could be superimposed on Figure 6, where they fall within the radiation-belt side of the dashed line. These points are not disturbed, with the exception of point (C), which falls close to the line. Of the three points at low altitudes (F, H, and J) only one, point F, is disturbed.

Of the two points (D and E) falling close to but outside the boundary, point D is not disturbed. However, it should be noted that the two measurements for point D were only 5 seconds apart in time and differed by 20 gammas relative to the reference fields. This may indicate the presence of rapid changes. Point E is so exceptional that it was at first not accepted. However, independent rechecks confirmed the three readings with high accuracy and the investigators have been unable to find a reason to doubt its validity. The fact that point F, taken 11 minutes later at a lower altitude and greater latitude showed —40 gammas in comparison with about +460 for point E, may indicate that the disturbance for point E was highly localized along a boundary, but this can only be a postulate for the present.

Point K was taken over the magnetic equator during the morning increase in field intensity caused daily by the equatorial electrojet. Relative to the same time on quiet days, the surface field was not decreased and interpretation of the disturbance value is not obvious.

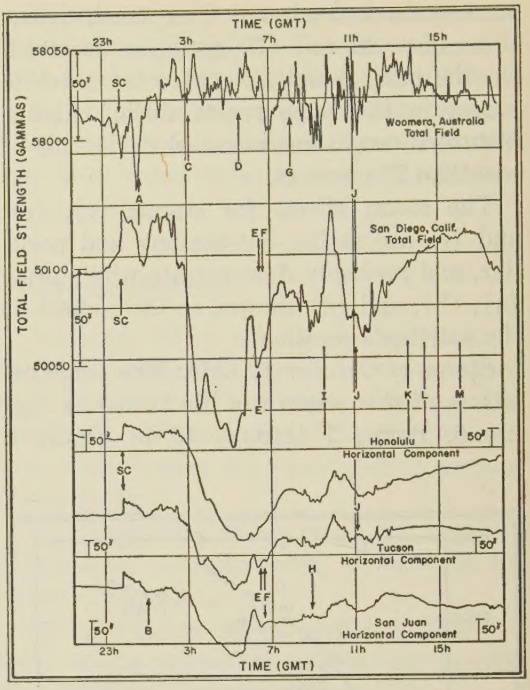

Fig. 7. *Variations of the Horizontal Component of the Earth's Magnetic Field during the Magnetic Storm of November 28, 1959, as Shown in Records of Three Ground Observatories, and Variations in Total-Field Records from Two Ground Observatories. Note similarity between curves for total field at San Diego and horizontal field at Tucson; points A-M correspond to satellite measurements shown in Table 1.*

For a number of hours following the time limits of Figure 7, the horizontal component shown in ground records remained depressed. A number of satellite measurements obtained from North America and Australia showed no disturbance, except for two passes that would fall near the dashed line of Figure 6. These showed disturbances of +20 and —20 gammas at altitudes of 3650 and 1200 kilometers, respectively.

Storm of December 5, 1959: Only a small number of measurements have been reduced

Table 1. Vanguard III Observations during Magnetic Storm on November 28, 1959
(Reference Table for Figure 7.)

Point	Time (GMT)	No. of Measurements	Average Geographic Coordinates		Height (Km)	Approx. Geomagnetic Latitude (degrees)	Satellite Total-Field Disturbance (gammas)
			Long. (deg)	Lat. (deg)			
A	00:44	3	137 E	19.5 S	2080	30 S	0
B	02:05	2	62 W	20.2 N	1560	31 N	0
C	03:07	3	136 E	31.5 S	3040	42 S	−40 to −60
D	05:33	2	128 E	32.3 S	3667	43 S	0
E	06:28	3	117 W	25.5 N	1290	33 N	+450 to +470
F	06:39	3	77 W	33.5 N	680	45 N	−40
G	08:01	2	137 E	21.6 S	3635	32 S	0
H	09:00	1	61 W	23.1 N	550	34 N	0
I	09:33	4	28 E	29.2 S	2740	30 S	0
J	11:05	2	117 W	30.8 N	530	38 N	0
K	13:37	4	76 W	9.5 S	1465	2 N	−20 to −40
L	14:24	3	28 E	26.4 S	3740	27 S	0
M	16:04	1	70 W	29.4 S	2723	18 S	0

thus far for the main phase of this storm and these include measurements from two regions where reference points are too sparse to permit analysis. The measurements from the following satellite passes are well referenced, however:

(1) Three measurements at altitude 1200 km and magnetic latitude 7° S were not disturbed. These were taken during the transition from the positive-horizontal-component phase (characteristic of the early part of the storm) to the main phase, and occurred at a time of equatorial-electrojet activity.

(2) Two measurements were taken over southern South America during the increasing-activity portion of the main phase of the storm. They show a negative disturbance at the satellite altitude of 2050 km.

(3) Four measurements at an altitude of 1000 km and magnetic latitude of 43° were not disturbed. These were taken during the decay of the main phase when the negative horizontal-component disturbance was about 40 gammas on the earth's surface.

Discussion of Storm Effects

Between magnetic latitudes of 25° and 45°, the magnetic-field observations of Vanguard III bear little if any resemblance to those of phenomena predicted in various magnetic-storm theories. It also appears doubtful that the various mechanisms proposed for creating magnetic storms can be used to explain these satellite observations, since, to fit them, a mechanism must be found for creating boundary currents, or their equivalent, on the inner Van Allen radiation belt (including the lower edge of the inner belt).

The most fundamental question is whether such boundary currents are a cause of magnetic disturbance or a result of a boundary reaction to an external phenomenon. Particle measurements made with satellites during magnetic storms have demonstrated that the "slot" between the radiation belts (or the inner part of the outer belt) shows marked changes during magnetic storms. The principal effects are: (i) during the main phase of a storm, radiation from the outer radiation belt is dumped into regions of lower latitude and altitude, and (ii) late in the recovery phase of a storm, the electron content of the outer zone increases. Radiation in the inner belt apparently remains unchanged during geomagnetic storms.

Two factors must be known before an adequate tie can be made between par-

ticle behavior and magnetic phenomena; they are: (i) the mechanism for accelerating or scattering particles out of the outer belt, and (ii) the energy and density of electrons in the inner belt. Without these, explanations must remain speculative.

The preferred explanation of the investigators, on the basis of available data, is that the boundary phenomenon is caused by activity external to the inner belt. Explanations for the boundary disturbances and for the lack of disturbance within the inner belt at magnetic latitudes greater than 25° can be sought by treating the inner belt as though it had super-conducting properties leading to induction currents on its outer surface, and by finding a mechanism that would give a sufficient particle gradient near the boundary to generate Hall currents.

Within the framework of the available data, however, it cannot be assumed that lack of change within the inner belt is conclusive evidence that it is a "dead" region during magnetic storms. At this point it cannot be explained why magnetic disturbances between 510 km and the lower edge of the inner belt at magnetic latitudes less than 25°, and at various altitudes in low magnetic latitudes, do not in general correlate with what is observed on the earth's surface. The role of ionospheric currents undoubtedly enters into this question but it would be surprising to find that they provide all the missing links.

One conclusion that can be drawn is that a transition in magnetic-storm phenomena can be expected in magnetic latitudes corresponding to the slot between the two radiation belts—roughly, magnetic latitudes 41°–46°. Additional evidence for this may be found in the behavior of the vertical component of the geomagnetic field at surface observatories during magnetic storms. Studies such as one carried out by S. Matsushita in these latitudes have shown that variations of the vertical component are consistently different at closely spaced stations. This is attributed to local induction effects caused by variations in ground conductivity. The question arises, however, of why these induction effects are so prominent. The answer may be that rapidly varying localized currents are generated in the slot region between the inner and outer belts during magnetic storms.

The Explorer IX Atmospheric-Density Satellite

The Explorer IX satellite, a gas-inflated, 12-foot, plastic and aluminum-foil sphere designed for use in atmospheric-density studies based on the effects of air drag on the satellite's orbit, was launched by the National Aeronautics and Space Administration from its Wallops Island, Virginia, station at 8:05 am EST, February 16, 1961. The satellite, also designated 1961 Delta in accordance with the astronomical identification system devised for satellites and space probes by the Smithsonian Astrophysical Observatory, was injected into orbit about 10½ minutes later and about 1280 miles downrange. (See Figure 8.)

After the satellite's beacon radio signal had been received initially by the NASA Minitrack station at Woomera, Australia, about an hour and 15 minutes after launch, the radio ceased functioning and the satellite was "lost" until sighted visually a few hours later by a South African Moonwatch

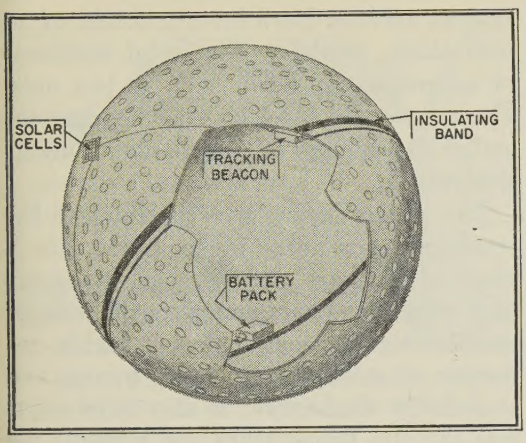

Fig. 8. *Explorer IX Inflatable Sphere Satellite. Cut-away section reveals locations of tracking beacon and battery pack; white dots help regulate temperature. From NASA photograph.*

team. Further visual and photographic sightings have shown Explorer IX to be approximately in its planned orbit, and, using optical observations to supply the necessary orbital data, the atmospheric-density experiment is proceeding.

Explorer IX was carried into orbit by a four-stage, all-solid-propellant Scout research rocket in the first successful launch using a vehicle fueled entirely by solid propellants. An important additional purpose of the Explorer IX launch was to flight-test the Scout rocket in order to gain further knowledge of its performance, structural integrity, and internal environmental conditions, and of the reliability of its guidance-control system. The Explorer IX launch was also the first successful United States satellite launch from NASA's Wallops Island Station—the first, in fact, from any United States site other than Cape Canaveral, Florida, on the Atlantic Missile Range, or Vandenburg Air Force Base, California, on the Pacific Missile Range.

Immediately after it was ascertained that Explorer IX was in orbit, a telegram giving orbital and experimental information was sent by the Space Science Board (SSB) of the US National Academy of Sciences to the Committee on Space Research (COSPAR), in the Hague, for transmittal to all COSPAR participants. Data obtained in the course of the atmospheric-density experiment will be forwarded to COSPAR and will also be deposited in the IGY World Data Centers.

Orbital Data

Explorer IX was launched eastward from Wallops Island on an elliptical flight path with initial perigee about 394 and apogee about 1607 statute miles above the earth. The belt covered by the initial orbits extends 38.9° north and south of the equator and the satellite's initial orbital period was calculated to be 118.55 minutes. Explorer IX was programmed for a velocity of approximately 17,866 mph at injection into orbit and at perigee. Its initial speed at apogee was about 14,000 mph.

Atmospheric-Density Experiment

The primary purpose of the Explorer IX inflatable-sphere experiment is to improve our knowledge of the density of the earth's atmosphere in the altitude range covered by the satellite's orbit, and of the variations in density with time and location, and under solar influence. Several different methods have been used through the years to measure atmospheric density. One method is to carry instruments aloft by balloons, which reach altitudes of about 20 miles. Another employs sounding-rocket techniques to measure air density to altitudes above 100 miles. (See *Bulletin Nos. 13, 14, 32,* and *40.*)

In recent years, particularly during the IGY, satellites such as the Sputniks, Vanguards, Explorers, and Echo I have extended knowledge of atmospheric density to nearly 1000 miles and have revealed that the density of the upper atmosphere is influenced markedly by solar storms. (See *Bulletin Nos. 32* and *44.*)

At present, atmospheric density at satellite altitudes is inferred from calculations

of tracking data obtained from the numerous satellites of different sizes and shapes, such as those named above. Because of the spherical shape of the Explorer IX satellite, however, the drag force acting on it depends only on atmospheric density and not on the satellite's attitude, as with nonspherical satellites. Thus, more accurate density values can now be obtained.

In the Explorer IX experiment, the orbiting spherical satellite is actually the measuring instrument. As the satellite, an object with a known mass and frontal area and highly sensitive to drag, slowly descends and dips more and more into the earth's atmosphere, it continually loses energy as a result of the minute force (estimated to be less than one-thousandth of an ounce for this satellite) exerted on it by the earth's atmosphere. Because of the relatively light weight of the 12-foot balloon, this small drag force results in measurable changes in its orbit. World-wide optical-tracking measurements of these orbital changes supply the information needed to determine the drag force accurately, and from this information, in turn, the atmospheric density can be computed for numerous points along the orbital path.

Description of Satellite

The Explorer IX plastic-sphere satellite was conceived, built, and packaged at NASA's Langley Research Center, and the laminated material used to construct the inflatable sphere was fabricated to NASA specifications by the Reynolds Metals Company.

Total payload weight is 75 pounds, of which the 12-foot inflatable satellite weighs 15 pounds. The fourth-stage rocket and the attached payload container weigh about 127 pounds.

Approximately twice the thickness of the cellophane on a cigarette package, the satellite skin is constructed of four alternate layers of mylar plastic film and aluminum foil, the final layer of foil making up the exterior surface. Each layer is 0.0005 of an inch thick, resulting in a total thickness of approximately 0.002 inch, or two mils. The sphere was fabricated by bonding together 40 flat gores of this aluminum-mylar laminate.

The plastic layers give the satellite the toughness it requires to be folded into a compact package for ease of transport into orbit. The aluminum gives the inflated satellite rigidity and makes it highly reflective of sunlight and radio waves, and electrically conductive; it also helps regulate satellite temperature and protects the plastic film from the intense ultraviolet radiation in this area beyond the protective filtering effects of the earth's atmosphere.

The rigidity provided by the aluminum foil keeps the satellite spherical, without internal pressure, as it circles the earth. After separation of the satellite and payload container, gas pressure in the sphere is equalized with the outside pressure by means of a valve. Any remaining inflation gas is expected to be lost through puncture of the satellite skin by micrometeorites.

Studies conducted at Langley indicate that the aluminum foil reflects about 85% of the sunlight falling upon it, permitting the sphere to be tracked optically throughout the world. To obtain better heat balance for the tracking beacon components, over 20% of the satellite surface area was covered with a pattern of two-inch-diameter white dots.

The deflated satellite was folded accordion-fashion inside a metal tube, 8½ inches in diameter and about 19 inches long, mounted on the front end of the fourth-stage rocket. Together, the satellite and its attached tracking-beacon components filled about the first 11 inches of the tube. In the space behind the folded satellite was an ejection bellows, a steel inflation bottle containing nitrogen gas under a pressure of about 1800 pounds per square inch, and the fourth-stage telemeter and its batteries. (See Figure 9.)

Radio Equipment: For tracking pur-

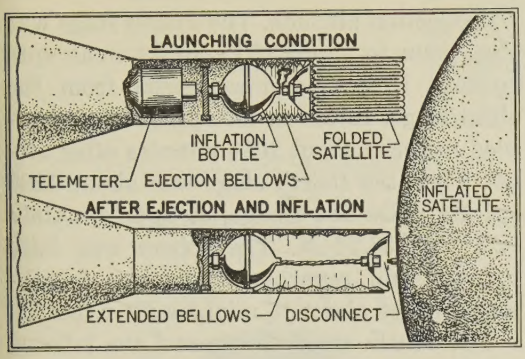

Fig. 9. *Explorer IX Payload Before and After Ejection and Inflation. From NASA photograph.*

poses, a 2¼-pound, 3 × 4-inch radio beacon powered by miniature storage batteries and 280 solar cells was attached to the sphere's inside surface near the equatorial gap (see Fig. 8). The storage batteries were to supply the necessary power while the satellite is in darkness.

The fourth-stage rocket casing of the Scout launch vehicle, in approximately the same orbit as the satellite, also contains a small tracking beacon. When the sphere's beacon ceased operating, it was possible to establish the approximate orbit of both satellite and rocket casing from signals received from the rocket-casing beacon by NASA Minitrack stations, thus making it easier to locate the sphere by visual and optical means.

Tracking

With failure of the radio-tracking beacon carried by Explorer IX, it became necessary to rely entirely on the network of high-precision Baker-Nunn tracking cameras, established during the IGY (see *Bulletin No. 12*), to supply the accurate orbital data needed for the atmospheric-density experiment. Optical tracking of the highly-reflective satellite is under the direction of the Smithsonian Astrophysical Observatory, and the fourth-stage rocket casing is also being tracked optically by the SAO network.

Scout Launch Vehicle

The launch was also part of NASA's Scout development program to provide the United States with a small, relatively inexpensive, reliable and flexible solid-fuel booster for space probes and satellites. The Scout research rocket has been under development by the NASA Langley Research Center since mid-1958. A number of Federal and private agencies participated in development and construction of the vehicle and its launch facilities.

The Scout vehicle is designed to place a 150-pound satellite into a circular orbit approximately 300 miles above the earth or to loft a 50-pound scientific probe vertically to an altitude of about 8400 miles. In reentry body tests, Scout will permit simulation of conditions expected by a space vehicle returning to the earth's atmosphere. With a ballistic trajectory, it will be possible to obtain almost two hours of zero-gravity environment with 100-pound experiments.

Description of Vehicle: The Scout first stage, named Algol for a fixed star in the constellation Perseus, is 30 feet long, 40 inches in diameter, and develops 103,000 pounds of thrust. The first stage is fin-stabilized and controlled in flight by jet vanes. It is the largest solid-fuel rocket flown thus far in the United States. The second stage, Castor, is 20 feet long, 30 inches in diameter, and has a thrust of more than 62,000 pounds. A modification of the Sergeant rocket, the Castor rocket used in the Scout vehicle is stabilized and controlled by hydrogen-peroxide jets. Castor is a star in the constellation Gemini.

The Scout third stage is named Antares for the brightest star in the constellation Scorpio. The rocket is 10 feet long and 30 inches in diameter, with a thrust in excess of 13,600 pounds. Stabilized and controlled by hydrogen-peroxide jets, and utilizing lightweight plastic construction throughout its design, Antares is a "scaled-up" version of Altair, the fourth stage. Altair, six

feet long, 18 inches in diameter, and having 2800 pounds of thrust, is named for a star of the first magnitude in the constellation Aquilae, or Eagle. The spin-stabilized Altair, the smallest of the four Scout stages, formerly known as X-248, has been used as the third stage on the Able and Delta launch vehicles and was the first fully developed rocket to utilize lightweight plastic construction throughout.

Launch Sequence: After launch, the Scout's first stage remained attached to the vehicle until second-stage ignition, 70 seconds later and at an altitude of 130,000 feet. The second stage carried the vehicle to about 310,000 feet and was blast-separated 116 seconds after launch when the guidance programmer ignited the third-stage rocket motor. After burnout, the spent third stage, with its guidance and control system operating, coasted for over seven minutes to the injection altitude. The fourth stage was then spun to about 150 rpm by small spin rockets, ignited, and separated from the third stage. Injection into orbit was scheduled to occur about 10½ minutes after lift-off, when the fourth stage was about 1280 statute miles downrange, at approximately 52.5° W, 35.2° N. The sphere was fully inflated and separated from the fourth-stage rocket about 15 minutes after launch.

The fourth-stage casing and the inflated sphere are expected to become increasingly separated in orbit because of differences in drag. Since the sphere is hundreds of times more sensitive to atmospheric drag, it is expected to remain in orbit from a few weeks to, possibly, a year before spiraling into the lower atmosphere and burning up. The predicted lifetime in orbit of the spent fourth-stage rocket motor is considerably longer.

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Preprinted from *Transactions, American Geophysical Union,* Vol. 42, No. 2, June, 1961